IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 17, Issue 4 Ser. IV (Jul. – Aug. 2020), PP 18-22
www.iosrjournals.org

A Review Article on Design, Analysis and Comparative Study of Conventional and Composite Leaf Spring

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Abstract: *Due to high strength to weight ratios, the automotive sector showed an increased interest in the composite fiberglass leaf spring as an alternative to steel leaf springs. Also, Composite materials in aeronautical, marine, and automotive industries are extensively accepted because of their outstanding mechanical properties, low density, and a production facility. The conventional leaf spring used is bulky so composite leaf spring should be used as a better alternative. The present study reviews the general study of design, analysis, and comparison of traditional and composite leaf spring. Leaf spring is commonly used in the suspension system of the automotive vehicle and is subjected to multiple stress cycles that lead to fatigue failure. That affects the significant behavior of the vehicle such as comfort in riding, stability, vibration characteristics, etc. A lot of studies and researches have been done to improve all these characteristics that are reviewed in this paper.*

Date of Submission: 20-08-2020 Date of Acceptance: 06-09-2020

I. Introduction

In comparison to another machine/structure parts, springs undergo substantial deformation when loaded-their compliance enables them to store readily recoverable mechanical energy. In the motion of the vehicle, as the wheel meets the obstacle, the mechanism allows the wheel to pass over the obstacle and then returns the wheel to its normal location. Springs are also common in force-displacement transducers, e.g. in weighing scales, where easily discerned displacement is a measure of the change in force [1]. The simplest spring is the voltage bar. This is an efficient energy store because all its elements are stressed in the same way, but its deformation is small if it is made of metal. In contrast to the constant cross-section beam, the leaf spring is stressed almost continuously along its length, since the linear increase of the bending moment either from simple support is accompanied by the widening of the beam-not by its depth, as longitudinal [2].
Figure 1 shows the picture of leaf spring along with its terminology.

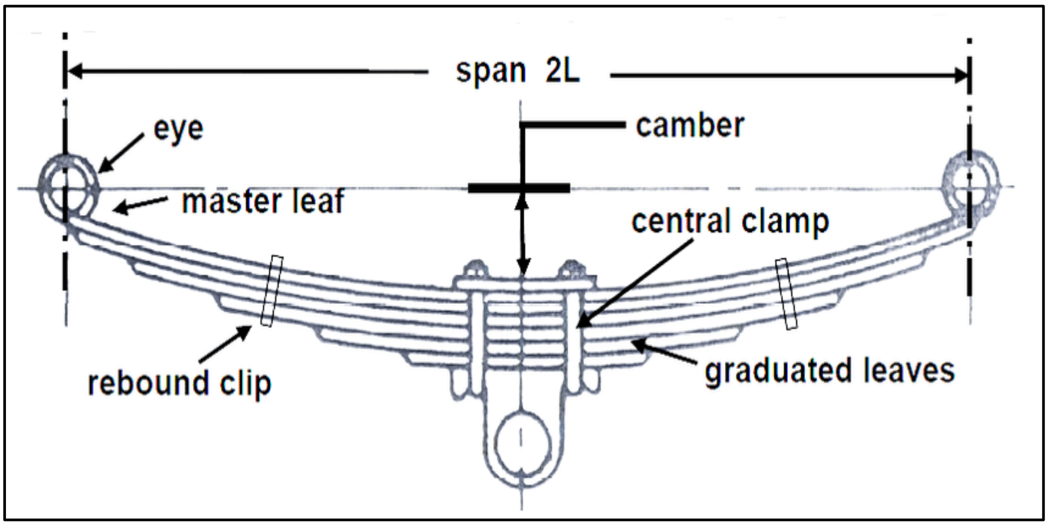

Figure 1*:* Leaf spring model

Leaf springs play the role of key elements in the suspension systems of automotive vehicles such as trucks, heavyweight vehicles, railroad vehicles, etc.The function of the leaf spring assembly is not limited to the suspension element. It is also exploited to isolate road-induced vibrations. Leaf springs' behaviour is very complicated due to its inner leaf contact, unlike its appearance [3].The material with maximum force and minimum Elasticity Modulus in the longitudinal direction is the most suitable material, according to studies conducted for leaf springs. To minimize accidents, the conventional steel leaf spring resulting from these failures can be replaced by composite leaf springs that are gradually failing. Stresses are slightly lower in the composite leaf spring than in the steel spring. The model spring is generated using the software for modeling, such as the pro-E, Catia, Solidworks, and imported into the analysis software like Ansys, Solid Edge,etc. The imported model is subject to boundary conditions [4].

In the current situation, a decrease in weight became the key priority of the vehicle manufacturer to protect natural resources and save money. Mainly by using new fabrics, optimization of design, and improved production methods, weight reduction can be accomplished. One of the possible things for weight loss in cars is the suspension leaf spring, which constitutes between 10 and 21% of the unsaved weight. This helps to achieve better riding qualities for the vehicle. Leaf springs are known to consume and store energy and release it. They are known. The stress-energy of the material therefore becomes an important factor in the nature of the springs.The expression for the specific strain energy relation cab be given as [5]:

$$U = \sigma^2 / \rho E$$

Where 'σ','ρ',and'E' are strength,density,andYoung'smodulus of the spring material with lower module and density is easily observed to have a more precise potential for stress energy. When using the composite materials, the weight of the leaf spring could be decreased without raising its load efficiency and rigidity. Because the materials in the composite are more elastic, the storage capacity is more versatile than steel in terms of weight and strength[6].

II. Material Selection

Selecting correct composite material for the composite leaf spring It depends on parameters like high strength, performance, durability, resistance to corrosion, weight benefits of the material. The leaf-spring content typically consists ofcarbon steel of 0.90 to 1.0% iron. After the formation process, the leaves are formed by heat processing. Heat treatment of spring steel products is stronger and therefore more resilient, more deflective, and fatigue-enhanced. For smooth application, it is essential to produce a specific structure in accordance with the working conditions and functional requirements of a composite leaf spring [7].
Fortunately, these features are present in fiber-reinforced composites.

1.1 Fiber

The reinforced fibers are currently widespread in producing carbon fibers and glass fibers are as hybrid leaf springs.Taking Figure 2 into account. HT-carbon / epoxy is dynamically loadedCapable of storing as much energy as possible. This material is also strong, stiff, and low in weight. Nonetheless, it has no impact strength and galvanically corrosion can cause some problems in the event of contact with a surface. One downside for practical use is the very high cost of this material [8].

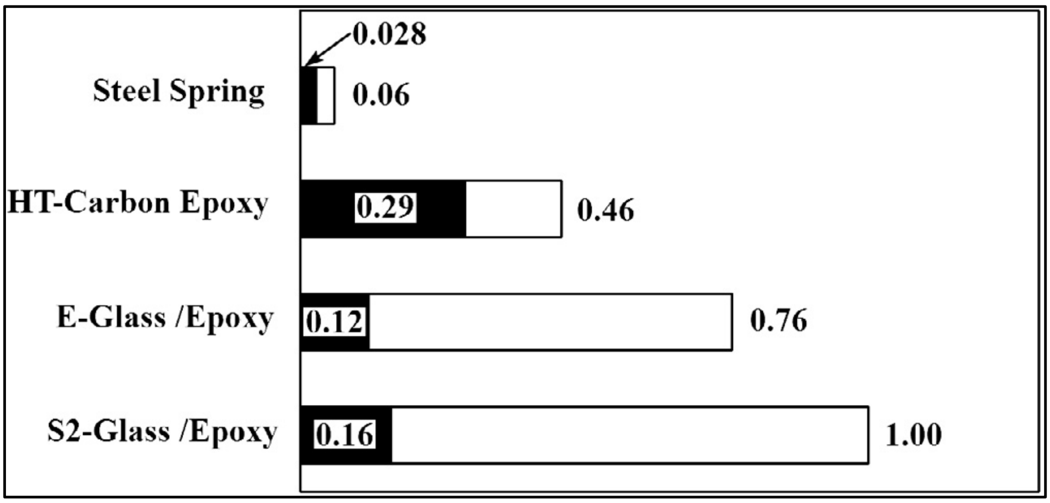

Figure 2: Specific strain energies of the leaf spring materials [6]

Glass fibres have lower strength and rigidity in contrast to carbon fibres, higher density, better resistance to corrosion, greater impact tolerance, and substantially lower costs. The glass fibres produce a good combination of material characteristics and cost. Two main forms of E and S2 are glass fibres. While the mechanical properties of S2 fibres are better than , E fibres are much lower than S2 fibres. For the most current research, therefore, glass fibres are used as reinforcing material [9].

III. Literature Review

B. Vijaya Lakshmi et al. [10]carried out static and dynamic analysis of composite leaf spring used in heavy automobile elements. The aim was to match the load-carrying capacity, stiffness, and weight savings of composite spring thereupon of steel spring. the planning constraints were stresses and deflections. The size for the current traditional steel spring of a major vehicle has been equal to the spring used to create an E-GLASS / EPOXY, C- GLASS / EPOXY, S- GLASS / EPOXY unidirectional laminates The same size is taken from the modern spring. Pro/Engineer software was used for modeling and COSMOS was used for analysis. Static & Dynamic analysis of spring was performed using COSMOS.

P. Beardmore et al. [11] described several examples of composite automotive Structures. Besides, the future potential for composites in these types of applications was discussed in terms of the fabrication developments which appear likely in the next decade.

C. J. Morris [12] described the design, fabrication, weight analysis, and testing of a composite integrated rear suspension of a Ford Escort vehicle. The results showed concept feasibility, a vehicle weight saving of 7 lb, good ride, noise, vibration, and harshness (NVH) characteristics. This study demonstrated the viability and potential of fiber-reinforced composites in automotive suspension systems.

Senthil Kumar et al. [13] described the design and experimental analysis of composite multi leaf spring made of glass fiber reinforced polymer. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle were taken and were verified by design calculations. Static analysis of the 2-D model of conventional one was also performed using ANSYS 7.1 and compared with experimental results. The dimension; of conventional leaf spring was used to fabricate a composite multi leaf spring using E-Glass/Epoxy unidirectional laminates. The objective was to get the load carrying capacity, stiffness, and weight savings of composite spring thereupon of steel spring. The design constraints were stresses and deflections. Finite element analysis v, its full bump load on the 3-D model of composite multi spring was done using ANSYS 7.1 6 and therefore the analytical results were compared with experimental results. The composite spring was found to be 67.35% lesser stress than steel spring, 64.95% higher stiffness than the existing steel steel spring, and 126.98% more natural frequency than existing. By using an optimized composite leaf spring a weight reduction of 76.4 % was achieved.

Li Zhanfang et al. [14] used a Genetic algorithm (GA) to solve the multi objective nonlinear optimization design of a hydro pneumatic spring. The four goals of riding comfort, a suspension stroke, road keeping and road friendliness with a fixed weight were normalized to establish the algorithm for the optimization of hydro-pneumatic springs. The linear fitness scaling was wont to enhance the worldwide searchability of GA and the adaptive penalty method was wont to handle the constraint conditions besides the range of design variables. Optimization design samples of 2 and 5 design variables were practiced. Analysis based on testing and simulating showed that the comprehensive performance of the hydro-pneumatic suspension increases by 50.66% and 118.18% respectively compared with the non-optimized one, which confirmed the validity of this method.

Ranjeet Mithari et al. [15] carried out stress analysis of composite material mono leaf spring. The current leaf spring was a multiple leaf spring type with steel material. It had high weight, low natural frequency, high corrosion, more noise. Therefore, multiple leaf 10 spring was replaced by mono composite (E- Glass epoxy) leaf spring which had high natural frequency, low weight. The maximum stress was produced at the cylindrical joint than the fixed joint. Therefore, stress analysis of composite material mono leaf spring was carried out. The result of the finite element method was verified with analytical calculation. Also compared the natural frequency by FFT analyzer was compared with FEA.

Mehdi Bakhshesh et al. [16] studied related to the lightweight vehicle suspension system. Steel helical spring were compared to an analytical solution in the result of a uniform loading and finites element analysis.Afterward, steel spring was replaced by three different composite helical springs including E-glass/Epoxy, Carbon/Epoxy, and Kevlar/Epoxy. Spring weight, maximum stress, and deflection were compared with steel helical spring and a factor of safety under the effect of applied loads was calculated. It was shown that spring optimization by changing spring material caused a reduction of spring weight and maximum stress considerably.

Joo-Teck Jeffrey Kueh et al. [17] investigated the static and fatigue behaviors of steel and composite multi spring(leaf) using the ANSYS V12 software. The dimensions of an existing conventional spring(leaf) of a light-weight commercial vehicle were used. The same dimensions were used to design composite multi-leaf spring for the two materials, E-glass fiber/epoxy and E-glass fiber/vinyl ester, which was of great interest to the transportation industry. The main consideration was given to the consequences of fabric composition and its fiber orientation on the static and fatigue behaviors of spring(leaf). The design constraints were bending stresses, deflection, and fatigue life. The designed composite spring has found significantly lower strains and deflections of the bending and higher fatigue cycles in comparison with the steel leaf spring.

Raghavendra et al. [18] described design and analysis of laminated composite mono spring(leaf), in this work, the size of an existing mono steel spring(leaf) of a Maruti 800 passenger vehicle was taken for modeling and analysis of a laminated composite mono spring with three different composite materials namely, E glass/Epoxy, S-glass/Epoxy, and Carbon/Epoxy subjected to an equivalent load as that of a steel spring. The design constraints were stresses and deflections. The three various types of composite mono leaf springs were modeled with considering certain cross-section, with unidirectional fiber orientation angle for every lamina of a laminate. A static analysis of a 3- D model was performed using ANSYS 10.0.

Krishan Kumar et al. [19]carried out work on a multi spring(leaf) having nine leaves utilized by an advert vehicle. The finite element modeling and analysis of a multi spring(leaf) was doled out. It included two full length leaves in which one was with eyed ends and seven graduated length leaves. The FE model of the leaf spring was generated in CATIA V5 R17 and imported in ANSYS-11 for finite element analysis. The material of the leaf spring was SUP9. The FEA of the spring(leaf) was performed by discretization of the model in infinite nodes and elements and refining them under defined precondition. Bending stress and deflection were the target results. A comparison of both i.e. experimental and FEA results was done to conclude.

Ahmet Kanbolat et al. [20] studied the more reliable approach by means of non-linear finite element solutions was introduced by measurement of effects of assembly parameters, geometric tolerances and characteristics variations. The leaf springs in different characteristics were produced and tested in the plant of Olgun Celik plant. The design methodology of this paper brought also a practical approach to the professionals in the industry. It aimed to create a design tool with 2D PEA which was well correlated with 3D. The correlation of 3D and simple 2D methods with experiments were validated through the design of experiment (DOE) study.

Mehdi Bakhshesh et al. [21] studied steel helical spring related to the light vehicle suspension system under the effect of a uniform loading and finite element analysis was compared with the analytical solution. Afterward, steel spring was replaced by three different composite helical springs including E-glass/Epoxy, Carbon/Epoxy, and Kevlar/Epoxy. Spring weight, maximum stress, and deflection were compared with steel helical spring and a factor of safety under the effect of applied loads was calculated. It was shown that spring optimization by changing spring material caused a reduction of spring weight and maximum stress considerably.

G. Harinath Gowd, et al [22] In this paper, attempts are made to analyse the safe load of the leaf spring, indicating the speed at which comfortable speed and safe drive are possible. The less configuration leaf spring configuration of the TATA-407 light commercial vehicle is chosen for the study. Finite element analysis was performed to determine safe stress and payloads. The leaf spring is modelled and the static analysis is performed using the ANSYS software and it is concluded that the leaf spring specifications are specified. Maximum stress on the inner side of the eye sections is observed, so care must be taken about eye design and manufacturing and material selection.

M. Nataraj, et al [23] The research reported in this paper studied the failure of the leaf spring suspension system used in TATA LPT 1613TCIC. The failed leaf spring fractured part was analysed using a visual inspection technique and a scanning electron microscope (SEM) analysis. The new leaf spring suspension system was designed in this research paper. Visual inspection and fracture analysis using SEM fracture analysis showed that the fracture was initiated due to cyclic loading.

S. Rajesh, et al [24]This paper addresses the substitution of conventional leaf spring for composite leaf spring. A light commercial vehicle has taken up and built its dimensions of the existing conventional leave spring using the specially designed die. ANSYS carried out and analysed the 3-D modelling of steel and composite leaf spring. The test results have been compared to FEM and the results have been well validated. The results show that the composite leaf spring was lightweight and cheaper than the standard steel leaf spring.

Jun Tajima, et al [25] studied the paper formulates this problem as a two-level optimizationissue of the two-bag air suspension system for heavy-duty vehicles.

Optimization of the airsuspension system with two bags.The original design issue is reformulated into two-level optimization problems,i.e. suspension-system-levelandcomponent-level optimization problems, by applying the Analytical Goal Cascading technique.

Amitkumar Magdum [26]Composite leaf spring deflection is greater than standard steel. The deflection of the Kevlar fabric is optimum. However, the equivalent stress in composite materials is less than in conventional steel. The energy absorbing potential is higher in Kevlar fabric than in S-glass composite and lower in steel. Also, the composite spring of Leaf has higher natural frequencies. It also involves the analysis of deflection and stress distribution of spring leaf for heavy-duty vehicles, taking into account various recent materials.

IV. Conclusion

Most of the design and performance research studies Composite leaf springs have been reviewed in this paper. Following are the findings based on the comprehensive review studied by the author.

In the last four decades, the design method for composite leaf springs has been well established and their structural applications have been enhanced. The laminated plate principle, FEM and GA are used for design and optimization of the spring structure. Optimizations research covered the structure, weight and rigidity of composite leaf springs, their strength and ply scheme. Nevertheless, there are no studies on improvements for composite leaf springs' dynamic performance such as dynamic rigidity, modal parameters, and creep. In addition to the increased costs, it has been found that the composite leaf springs' comprehensive performance is much better than steel leaf springs.

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Sagarsingh Kushwah, et. al. "A Review Article on Design, Analysis and Comparative Study of Conventional and Composite Leaf Spring." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 17(4), 2020, pp. 18-22.